NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

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RTO TECHNICAL MEMORANDUM **TM-SPD-002**

NATO RTO Space Science and Technology Advisory Group (SSTAG) Recommendations for Space Research Topics

(Recommandations du Groupe consultatif sur la science et la technologie spatiales (SSTAG) de la RTO de l'OTAN sur les sujets relatifs à la recherche spatiale)

Prepared by RTO Space Science and

Technology Advisory Group (SSTAG).

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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List of Acronyms

AFRL	Air Force Research Laboratory
ATR	Automated Target Recognition
BDA	Battle Damage Assessment
BNSC	British National Space Centre
CEPinDAT	Civil Emergency Planning in Defense Against Terrorism
CERTO	Coherent Electromagnetic Radio Tomography
CITRIS	Scintillation and Tomography Receiver in Space
CIS	Communication and Information Systems
CMG	Control Moment Gyro
CNES	Centre National d'Etudes Spatiales
CNSA	China National Space Administration
CONOPS	Concepts of Operations
COP	Common Operational Picture
CRPA	Control Reception Pattern Antenna
CRS	Commercial Remote Sensing
DAT	Defense Against Terrorism
DGA	Délégation Générale pour l'Armement
DLR	Deutsches Zentrum für Luft-und Raumfahrt e.V.
DRDC	Defence Research and Development Canada
DSTL	Defence Science and Technology Laboratory
EA	Electronic Attack
EHF	Extremely High Frequency
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Electro-Optic
EP	Electronic Protection
ES	Electronic Support
ESA	European Space Agency
EU	European Union
EW	Electronic Warfare
FFI	Norwegian Defense Research Establishment
GEO	Geostationary Orbit
GIS	Geospatial Information Systems
GMES	Global Monitoring for Environment and Security
GMTI	Ground Moving Target Indicator
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HQ	Headquarters
HW	Hardware

I&W	Intelligence and Warning
IADC	Inter-Agency Space Debris Coordination Committee
IBS	Integrated Booking System
IMINT	Imagery Intelligence
INS	Inertial Navigation System
IPAC-CMG	Integrated Power Attitude Control-Control Moment Gyroscope
IR	Infrared
ISR	Intelligence, Surveillance and Reconnaissance
ISRO	Indian Space Research Organization
ISTAR	Intelligence, Surveillance, Target Acquisition and Reconnaissance
ITU-R	International Telecommunications Union – Radiocommunications
JAPCC	Joint Air Power Competency Centre
LDR	Low Data Rate
LEO	Low-Earth Orbit
Mbps	Megabits/second
MDN	Direccao-Geral de Armamento e Equipamentos de Defesa
MEMS	Micro-Electro-Mechanical Systems
MFS	Multi-Functional Structures
MILSAT	Military Satellite
MSS	Mobile Satcom Service
MTI	Moving Target Identification
MUOS	Mobile User Objective System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVWAR	Navigational Warfare
NC3A	NATO Consultation, Command and Control Agency
NC3B	NATO Consultation, Command and Control Board
NEC	Network Enabled Capability
NIIRS	National Imagery Interpretability Rating Scale
NIVR	Netherlands Agency for Aerospace Programs
NNEC	NATO Network enabled capability
NRF	NATO Response Force
NSAU	National Space Agency of Ukraine
NURC	NATO Underwater Research Center
PfP	Partnership for Peace
PNT	Position, Navigation and Timing
PRS	Public Regulated Service
R&D	Research & Development
REP	Recognized Environmental Picture
RF	Radio Frequency
ROSA	Romanian Space Agency
ROSAVIAKOSMOS	Russian Aviation and Space Agency
RTA	Research and Technology Agency
RTO	Research and Technology Organization

SAASM	Selective Availability / Anti-Spoofing Module
SAR	Synthetic Aperture Radar
SDMA	Space Division Multiple Access
SEC	Space Expert Consultant
SEP	Solar Energetic Particles
SET	Sensors & Electronics Technology
SSTAG	Space Science and Technology Advisory Group
SW	Software
TDMA	Time Division Multiple Access
TEC	Total Electron Count
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UK	United Kingdom
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
USA	United States
UXO	Unexploded Ordnance
VHF	Very High Frequency

SSTAG Membership List

Membership of the RTO Space Science and Technology Advisory Group (SSTAG) was approved by the NATO RTO RTB on 4 May, 2005. The following individuals are the current members:

Lt. Col. Erwin DUHAMEL (BEL)	National Armaments Directorate
Mr. Brian EATOCK (CAN)	Defence Research and Development Canada
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Mr. David BEARD (GBR)	Defence Science and Technology Laboratory (DSTL)
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The RTO Space Science and Technology Advisory Group (SSTAG) and the RTA Space Research and Technology Executive Officer gratefully acknowledge contributions to this report from members of the RTO Space Expert Consultant (SEC) Network. About 50 SEC from 13 nations contributed to discussions at the RTA Space Strategy Workshop held at RTA Headquarters at Paris, France, 9-10 June, 2005. From this event, detailed summaries for each technical topic were prepared by the following people for this report:

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NATO RTO Space Science and Technology Advisory Group (SSTAG) Recommendations for Space Research Topics

(RTO-TM-SPD-002)

Executive Summary

As NATO and Nations are facing increased global responsibilities for security and defence with smaller forces, the ability to meet objectives will increasingly depend on use of integral, force-enhancing support from space.

In recognition of this trend for the future, the RTB established a limited-life, RTO Space Science and Technology Advisory Group (SSTAG) at the 18th RTB Spring Executive Session in 2005. The purpose of the SSTAG is to identify and recommend space research topics to the RTB and RTO panels for consideration.

In particular, the intended goal is to ensure adequate and appropriate levels of space research in the NATO RTO in order to enhance NATO security and defence effectiveness by increasing national capability to achieve and maintain superiority via the use of modern space systems. Thus, the objective is to strengthen the ability of RTO research panels to initiate and support space research via identification of specific technical research topics that are consistent with NATO's capability needs and national interests.

Recommendations were defined through a peer review process involving panel members and external colleagues from the extensive RTO Space Expert Consultant (SEC) network established over the past 2 years by RTO national representatives and panel members.

The process included the Space Strategy Workshop held at RTA HQ in June, 2005. At this workshop, 13 nations attended and each summarized national space research priorities. Breakout sessions were held to identify specific research areas of common interest. These sessions were led by members of the SSTAG or colleagues.

From this workshop, 29 topics of common interest were identified. A motivation and specific areas of potential cooperation were developed for each topic by members of the SEC network through Summer and Fall, 2005. SSTAG also sought national support for the topics through Fall, 2005. This effort resulted in the identification of specific individuals within the nations who would potentially be available to support each topic. Participation of such individuals in any resulting activities would need to be coordinated through appropriate national representatives. Finally, this effort was supplemented by a SSTAG high level view of relevance to NATO Capability Needs.

In general, broad national support was observed for several topical areas. One of these areas involves space based remote sensing technology and applications including RADAR, multi- and hyperspectral imaging, maritime surveillance and oceanography and 3D urban mapping. Another area of broad national interest is the development of small satellite vehicle technology, sensors, and control of small satellite systems. Communication in the NATO networked environment is also of high interest as well as the development of interfaces for early warning systems.

The SSTAG is seeking Panel consideration of the SSTAG recommendations as new or extended panel technical activities. In particular, the SSTAG is requesting each Panel to identify topics which have potential as technical activities within the Panel; to indicate if the Panel is willing to take a leadership role in any of the topics as a Panel or Inter-Panel technical activity; and to identify on-going activities within the 2006/7 Program of Work that may be addressing technical topics related to the recommendations.

Recommandations du Groupe consultatif sur la science et la technologie spatiales (SSTAG) de la RTO de l'OTAN sur les sujets relatifs à la recherche spatiale

(RTO-TM-SPD-002)

Synthèse

Au moment où l'OTAN et les nations se trouvent confrontés à des responsabilités mondiales accrues en matière de sécurité et de défense avec des forces plus réduites, la capacité à répondre aux objectifs dépendra de plus en plus d'un soutien intégré d'amélioration des forces fourni par l'espace.

Conscient de cette tendance pour l'avenir, le RTB a crée un Groupe consultatif sur la science et la technologie spatiales (SSTAG) au sein de la RTO, limité dans le temps, lors de la 18ème session de printemps du RTB en 2005. L'objectif du SSTAG est d'identifier et de recommander des sujets de recherche spatiale à prendre en compte par les panels RTB et RTO.

En particulier, l'objectif recherché est d'assurer des niveaux adaptés et appropriés de recherche spatiale au sein de la RTO de l'OTAN afin d'améliorer l'efficacité de l'OTAN en matière de sécurité et de défense, en augmentant les capacités nationales en vue d'atteindre et de maintenir une supériorité grâce à l'utilisation de systèmes spatiaux modernes. Donc, l'objectif est de renforcer la capacité des panels de recherche de la RTO à lancer et à soutenir la recherche spatiale grâce à l'identification de sujets de recherche technique spécifiques cohérents avec les intérêts nationaux et les besoins de l'OTAN en matière de capacités.

Des recommandations ont été définies par un processus de revue de pairs impliquant des membres des commissions et des collègues extérieurs issus du réseau des Consultants experts spatiaux (SEC) de la RTO établi durant les deux dernières années par les représentants nationaux de la RTO et les membres des commissions.

Ce processus comprenait l'Atelier de stratégie spatiale qui s'est tenu au quartier général de la RTA en juin 2005. Lors de cet atelier, 13 nations ont été représentées et ont chacune présenté une synthèse des priorités nationales en matière de recherche spatiale. Des sessions d'ateliers ont été tenues afin d'identifier des domaines de recherche spécifiques d'intérêt commun. Ces sessions étaient animées par des membres du SSTAG ou par leurs collègues.

Cet atelier a permis d'identifier 29 sujets d'intérêt commun. Une motivation et des domaines spécifiques de coopération potentielle ont été développés pour chaque sujet par des membres du réseau SEC au cours de l'été et de l'automne 2005. Le SSTAG a également recherché des soutiens nationaux pour ces sujets au cours de l'automne 2005. Cet effort a conduit à l'identification de personnels spécifiques au sein des nations, qui seraient potentiellement prêts à soutenir chaque sujet. La participation de ces personnels à d'éventuelles activités ultérieures devra être coordonnée par l'intermédiaire des représentants nationaux correspondants. Enfin, cet effort a été complété par un aperçu global du SSTAG sur son utilité par rapport aux besoins de l'OTAN en matière de capacités.

En général, un large soutien national a été observé pour plusieurs types de sujets. L'un de ces domaines concerne la technologie spatiale de détection à distance et les applications telles que le RADAR, l'imagerie multispectrale et hyperspectrale, la surveillance maritime et l'océanographie, ainsi que la cartographie urbaine 3D. Un autre domaine suscitant un large intérêt national est le développement de la technologie des petits véhicules satellitaires, des capteurs, et du contrôle des petits systèmes satellites. La communication dans l'environnement réseau de l'OTAN représente également un grand intérêt, tout comme le développement d'interfaces pour les systèmes d'alerte lointaine.

Le SSTAG recherche la prise en compte par les commissions des recommandations du SSTAG dans le cadre d'activités techniques nouvelles ou élargies des commissions. En particulier, le SSTAG demande à chaque commission d'identifier les sujets présentant un potentiel d'activités techniques, d'indiquer si la commission souhaite assurer la conduite de l'un des sujets dans le cadre d'une activité technique de commission ou inter-commissions, et d'identifier les activités permanentes dans le cadre du programme de travail 2006/7 susceptibles de traiter des sujets techniques relatifs aux recommandations.

NATO RTO Space Science and Technology Advisory Group (SSTAG) Recommendations for Space Research Topics

1.0 INTRODUCTION

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2.0 SSTAG RECOMMENDATIONS RANKED ACCORDING TO NATIONAL INTEREST

ID	Topic	Number of Nations Interested
27	Space-Based Multi- and Hyperspectral Sensors Technology and Applications	11*
12	Small Satellite Technologies	10
26	Space-Based Radar Technology and Applications	10*
13	Satellite Constellations and Formation Flying in the Networked Environment	9
2	NATO Network Enabled Capability over SATCOM	8*
7	Use of Commercial Satellite Remote Sensing Information for Maritime Surveillance and Oceanography	8*
9	3D Urban Mapping	8
8	Exploitation of Satellite Remote Sensing Data for Change Detection	7*
29	Radar Polarimetry from Space	7*
1	Ground Segment Antenna for Multi-Mission Applications	6*
10	Space Object Surveillance	6*
17	Satellite Navigation, Attitude Control, Orbit Determination and Tracking	6
19	Systems of Systems for Early Warning	6*
11	Space Debris	5*
15	Spacecraft Robotics	5
18	Space Environment and Space Weather Effects	5
21	Image and Data Compression Algorithms for Remote Sensing and Communication	5
22	Near Real-Time Automatic and Semi-Automatic Multi-Sensor Data Fusion	5*
28	Use of Surveillance Sensors for Moving Target Indication (MTI)	5
3	UHF Antenna Systems for SATCOM Applications	4
4	Optical Communications and Architectures	4
5	Navigational Warfare	4*
6	Geospatial Information Systems (GIS)	4*
14	Emerging Spacecraft Structures and Materials	4
20	Atmospheric Propagation and Mitigation Techniques	4
24	Upper Atmospheric Research	4
25	Ionospheric Research	3
16	Spacecraft Power Systems and Propulsion	2
23	Satellite and Sensor Protection	2

* Additional interest in participation by NC3A/B[1], NURC[2] and/or NATO JAPCC[3].

[1] NC3A (NATO Consultation, Command and Control Agency); NC3B (NATO Consultation, Command and Control Board)

[2] NURC (NATO Underwater Research Center)

[3] JAPCC (Joint Air Power Competency Center)

3.0 SSTAG PERSPECTIVE ON RELEVANCE OF TOPICS TO NATO CAPABILITY NEEDS

ID	Topic	SSTAG View of Relevance to NATO Capability Needs
1	Ground Segment Antenna for Multi-Mission Applications	Topic contributes to effective interoperability, sharability of information and cost reduction through a generic architecture and supports NRF Expeditionary Operations.
2	NATO Network Enabled Capability over SATCOM	Topic contributes to Information Superiority and NATO Network Enabled Capability (NNEC). Any NNEC will inevitably involve use of SATCOM. Much work is being done in the development of commercial communication capabilities. Architecture studies are needed to most effectively include commercial capabilities in the military environment where rapid tactical information exchange is required.
3	UHF Antenna Systems for SATCOM Applications	For tactical combat operations as well as for special intelligence missions, the UHF SATCOM is still one of the most competitive systems to guarantee reliable low cost and low data rate mobile communications when operating in a very severe climatic and vegetation environment.
4	Optical Communications and Architectures	Optical communications to satellite and the reach-back architecture directly supports NATO NEC, Information Superiority and Effective Engagement. In combination with RF communications, optical communications to satellites have increased bandwidth and can remove the need for an in-theatre ground-station, which limits ISTAR platform reach and constrains information sharing.
5	Navigational Warfare	This topic is key to almost all of the NATO military needs and capabilities. It is most critical to maintaining the COP and overall effective engagement by protection of PNT. Continued interoperability amongst NATO forces will hinge upon this area.
6	Geospatial Information Systems (GIS)	Geospatial information is required for Effective Engagement and Maneuvering and Expeditionary Operations. Space-based remote sensors generate large amounts of geospatial data. A GIS is needed to manage and combine remote sensed and other data and provide it in timely accurate and updated manner.
7	Use of Commercial Satellite Remote Sensing Information for Maritime Surveillance and Oceanography	Commercial remote sensing in a relatively low cost source of space-based imagery for support of Expeditionary Operations. Further refinement of tools to support Recognized Environmental Picture (REP) and Intelligence, Surveillance and Reconnaissance (ISR) and merging of CRS with operational systems are necessary.
8	Exploitation of Satellite Remote Sensing Data for Change Detection	This will contribute to the REP, expeditionary forces, Counter Measures, Defense Against Terrorism (DAT) and Battle Damage Assessment (BDA).
9	3D Urban Mapping	Topic supports Joint Urban Operations. This has broad applicability to Expeditionary Operations and DAT.
10	Space Object Surveillance	Space object surveillance contributes to improved Situational Awareness of the status and use of space-based assets.
11	Space Debris	Space debris as small as 1 cm can destroy a satellite in low-Earth orbit, and the space debris population is increasing despite current international efforts to curb this rise. In addition to determining NATO use of international guidelines and mitigation standards, improved methods of monitoring small debris at all orbital altitudes and modeling population increases are needed to protect the vital space-based capability that NATO relies upon.

ID	Topic	SSTAG View of Relevance to NATO Capability Needs
12	Small Satellite Technologies	Small satellites enable affordable solutions which allow more nations to contribute to the enhancement NATO capability. There are technological hurdles to overcome to achieve improved cost-performance ratio for mass and size. Small satellite technologies are a major enabler to meet a broad range of NATO's future capability needs.
13	Satellite Constellations and Formation Flying in the Networked Environment	Collaborative satellite operation has the potential to increase the effective performance of individual sensors, has the potential to add flexibility and robustness to a Networked Environment and to improve the system response time. Topic is good candidate for systems study to evaluate the cost-benefits. (see #12 Small Satellite Technologies)
14	Emerging Spacecraft Structures and Materials	The military use of the Multi-Functional Structures (MFS) technology is fundamental to reduce the overall satellite mass for any type of mission that is being addressed and allows the integration of multiple technologies in a smaller volume. Thus, MFS contribute to a reduced cost of space-based systems making them more affordable and capable elements of NATO's Network Enabled Capability.
15	Spacecraft Robotics	In the next future the space robotic technology could provide NATO or National Military satellite network, operating for earth observation, early warning or space-based launcher platform, with in orbit maintenance services, re-supply or other logistic in orbit operation. The benefit to have an extended satellite lifetime and a longer autonomous capability to reconfigure itself will represent a real revolution in terms of cost reduction and types of mission to plan.
16	Spacecraft Power Systems and Propulsion	The topic is pervasive to persistent satellite operations and therefore is relevant to all space-based assets used for communications, navigation, surveillance and other critical military activities. It is relevant to maintaining Information Superiority, NNEC, Effective Engagement and Joint Maneuver as well as impacting DAT.
17	Satellite Navigation, Attitude Control, Orbit Determination and Tracking	Research of these topics is essential for the future military applications that include areas such as satellite clusters and formation flying, multi-mission and multi-user satellite operations, processing of Synthetic Aperture Radar (SAR) images with very high resolution, generation of digital elevation models and automatic georeferencing. Realization of such technology contributes to achieving improved Joint Intelligence, Surveillance and Reconnaissance and improved Joint Strike and Effect.
18	Space Environment and Space Weather Effects	Space-based elements of NATO global infrastructure for a networked environment, of Global Positioning System (GPS) and of Joint intelligence, surveillance and reconnaissance must function in the variable space environment. Space weather often influences and disturbs space-based and ground-based systems. The topic is important for mitigation of these effects on military and civilian systems and permits operational use of the same effects on opposing forces' systems.
19	Systems of Systems for Early Warning	The Ballistic Missile Defense system, to protect deployed forces in theatre areas or to protect the entire NATO territory and population centers, is representing one of the most important capability need for the Alliance in the near future. The proposed topic is fundamental to provide a real contribution to C4ISTAR (Intelligence, Surveillance, Target Acquisition and Reconnaissance) operation capability.

ID	Topic	SSTAG View of Relevance to NATO Capability Needs
20	Atmospheric Propagation and Mitigation Techniques	The topic improves spaced-based remote sensing and communication that are necessary for the NATO global infrastructure for a networked environment and for joint intelligence, surveillance and reconnaissance, as well as Automated Target Recognition (ATR) and REP.
21	Image and Data Compression Algorithms for Remote Sensing and Communication	In order to establish a NNEC in an efficient and cost effective manner, data and in particular images will have to be compressed. Information superiority will be determined by the security architecture and the processing power of the space segment.
22	Near Real-Time Automatic and Semi-Automatic Multi-Sensor Data Fusion	Data fusion techniques combine data from multiple sensors and related information from associated databases, to achieve improved accuracy and more specific inferences that could be achieved by the use of single sensor alone.
23	Satellite and Sensor Protection	In order to assure NATO Information Superiority, the reliability of satellites must be maintained. The requirements for reliability are continuously increasing due to the military importance of their functionalities, e.g. GPS, Galileo, Ikonos, QuickBird, SATCOM. Research must be carried out to harden satellite buses, to protect sensors and communication links.
24	Upper Atmospheric Research	The topic contributes to directed energy weapons as well as to topics 4, 8, 9 and 27 of this list.
25	Ionospheric Research	The topic will improve use and access to bandwidth and frequency spectrum, as well as worldwide, reliable, precise positioning and navigation, thus, contributing to NATO's need for Information Superiority.
26	Space-Based Radar Technology and Applications	The all-weather capability of SAR contributes continuously to the REP and many other ISTAR applications. Space-based SAR systems are already in orbit but still offer a large potential of improvement for military applications such as using larger bandwidth, wider field of view and new operating modes. Research is needed to improve cost effectiveness of space-based SAR.
27	Space-Based Multi- and Hyperspectral Sensors Technology and Applications	Topic has a potential to contribute to ISR priorities of Effective Engagement and Joint Maneuver, Countermeasures and Force Protection, Expeditionary Operations. Although sensor technology has made rapid advancement in recent years, there is still a need to better understand the phenomenology and exploitation of the data.
28	Use of Surveillance Sensors for Moving Target Indication (MTI)	Reconnaissance, surveillance and target assessment are a must for the NATO capability needs. Military or dual use satellite Radar sensors such as RADARSAT-2 or Cosmo SKYMED, are just some of the reasons to encourage the development of Moving Target Indication algorithms to enable surveillance/tracking capability on wide geographical areas.
29	Radar Polarimetry from Space	Topic offers considerable improvement for ATR and the REP.

4.0 SSTAG RECOMMENDATIONS INDICATING NATIONAL INTEREST

The current section includes definition of the recommended space research topics. A summary of motivation and potential collaborative work is provided for each. The summaries are intended to be starting points for potential participants in panel activities that might result from these recommendations. Summaries were written by one or more members of the SEC network.

Each summary indicates national interest. This is an indication that a national representative, in most cases a member of the SSTAG, has identified specific individuals in each nation who are potentially available to participate in a given topic if it would become a panel activity. Panel members should contact their national SEC point of contact provided in Chapter 2 to obtain names of these individuals. Participation of such individuals in any resulting activities must be coordinated through appropriate National Panel representatives and National Coordinators (Chapter 5). Interest in participation by NATO researchers is also indicated.

4.1 Ground Segment Antenna for Multi-Mission Applications

4.1.1 Motivation

Since interoperability is a key issue in NATO and CIS moves toward Network Enabled Capability (NEC) it is of the greatest importance that antennae be developed for users who need to communicate with different Concepts of Operations (CONOPS): from the definition of a ground segment with a generic architecture (including software and hardware standardization), interoperable from request to analysis with deployable and/or multi-frequency antennae for different type of user needs (for instance, on the move, ship or airborne) to testing and calibration of the antennae.

4.1.2 Areas for Collaboration

The research should be focused on the definition of a ground segment with a generic architecture (including software and hardware standardization), interoperability from request to analysis (in real time including data standards and interfaces), deployable antennae and the steering mechanisms, multi-frequency antennae, interoperable antennae for different type of users, testing, calibration and quality control of antennae.

4.1.3 National Interest

BEL, CAN, FRA, GBR, ITA, USA, NURC (6).

4.2 NATO Network Enabled Capability over SATCOM

4.2.1 Motivation

The NATO NEC is a key driver for the transformation of military operations. The purpose is to achieve quicker, safer and more efficient operational loops among sensors, intelligence processors, decision makers and battlefield actuators. One basic idea is to offer new and more efficient collaborative services by connecting all actors in a global network from the strategic to the tactical domain. Satellites are an obvious candidate to help for these functions, because of their good properties, like:

- Link costs and delays independence of distance
- Easy and widespread high data rate IP access
- Quick Configuration time
- Safe Space assets
- Light ground infrastructures

From current MILSATCOM generations, MILSATCOM must still achieve improved performances in several fields:

- Lighter and lower cost terminals
- Higher throughputs
- Adapted coverage
- Electronically Protected Communications
- Provision of frequency reuse for increased capacity per satellite
- Meshed broadcast services
- Backhauling to long range communications of battlefield radios
- UAV relays

4.2.2 Areas for Collaboration

Several NATO Nations are starting transformational Studies. This is the case in the United States of America (USA), in France, in the United Kingdom (UK) in Sweden and others. Areas for collaboration are multiple. At first, since most military operations happen to be driven in multi-national participation, interoperability must be achieved for better efficiency. Experience feedbacks could be shared in order to avoid restarting elsewhere with wrong good ideas:

1) Considering classical bent pipe satellite capacity solution, several communication technologies should be compared in order to select the most appropriate for NATO NEC service. Among those, one may quote:
   - Star FDMA SCPC DAMA
   - Meshed IBS standard Transit
   - Dynamically managed Meshed TDMA
   - Star or meshed dynamically managed Interactive broadcast (DVB-S/DVB-RCS)

2) Second, since MILSATCOM development need expensive non recurring costs, it may be thought efficient to share these costs through international co-operation. At first these developments could address:

- Ad hoc Technology demonstration for technology selection
- Battle labs for new operational concepts elaboration and validation

3) Much of the NEC SATCOM is similar with civilian issues like natural disasters or terrorist attacks warning and healing as well as border or forbidden traffics surveillance. So exchanges could be fruitful with the civilian Space Agencies involved in Global Monitoring and Earth Survey Programs (GMES), especially National Aeronautics and Space Administration (NASA) and European Space Agency (ESA).

4) Security is an other issue, since there must be place for both:
   - Interoperable Security among Partner Nations
   - National Private Security

4.2.3 National Interest

CAN, FRA, GBR, ITA, NLD, ROU, TUR, USA, NURC (8).

4.3 UHF Antenna Systems for SATCOM Applications

4.3.1 Motivation

Current UHF SATCOM are useful for low cost, Low Data Rate (LDR) mobile communications even in very severe climatic and vegetation environments but are still extremely limited by the available bandwidth, the low antenna directivity and the consecutive difficult issue of frequency co-ordination among different international systems. Adequate new technologies are currently sought after for the commercial mobile SATCOM Service (MSS) and in the US MUOS Program but are not yet fully available in orbit. For example:

1) Very large size satellite antennas
2) Digital Beam forming allowing:
    - Space Division Multiple Access (SDMA)
    - Frequency reuse
    - Maximum to small user terminal directivity
3) Digital On Board Processing and Switching

This is an excellent opportunity for improved world wide services with higher throughput and wideband IP direct access to users equipped with mere handset terminals. These terminals may be compatible with ground or tactical radio in order to reserve rare SATCOM assets use only when no ground radio is available.

4.3.2 Areas for Collaboration

Access to high data rate Mobile SATCOM Service for handset terminals technologies is still very expensive. Several skills must be combined:

1) Mechanical skills for very large size satellite reflectors
2) Antenna skills for Digital Beam forming and calibration
3) Communication skills for Digital Return link multi-carrier demodulation and forward link modulation according DVB-S/DVB-RCS latest standards
4) Management skills for Dynamic Access Management
5) Ground Terminal skills for new mobile smaller platforms: combat air-crafts, helicopters, land vehicles, small ships, not forgetting hand sets

These skills may have been developed in some Countries and could be gathered for integration in a multi-national program.

Another topic for consideration is exactly the opposite. Since UHF cannot be protected against interferences and will always be bandwidth constrained, the possibility to replace all existing UHF services by either commercial L band services (INMARSAT, THURAYA), X band services (ships, submarines) or backhauling via tactical radio in the ground segment and Ka wideband satellite in the Space segment could be investigated.

4.3.3 National Interest

FRA, GBR, ITA, USA (4).

4.4 Optical Communications and Architectures

4.4.1 Motivation

Current concepts of operation for Intelligence, Surveillance and Reconnaissance (ISR) from airborne platforms are limited by the available communications bearers, and in particular require the use of an in-theatre ground-station to receive the data at very data rates. Deploying such a ground station limits the range of sensor platform operations and requires a military presence to defend the territory on which the ground station stands. Optical communications (in combination with RF communications) could provide the capability for sensor data to be passed via a Geo-stationary satellite to a fixed base, removing the need for an in-theatre ground-station. Equally as important, this data is then able to be processed and passed around coalition partners at high speed over fixed fiber networks, whereas data at in-theatre ground stations is hard to share due to their communications limitations. Thus optical communications and the reach-back architecture support the NATO NEC concept. (Other non-ISR operations can also benefit from high-data rate reach-back.)

4.4.2 Areas for Collaboration

NATO partners may wish to exchange information regarding national Operational Analysis and Feasibility studies that propose Concepts of Operation for Intelligence Surveillance and Reconnaissance that involve use of very-high data rate reach-back via a GEO satellite (>600 MBps). Such studies should look at different architecture options and evaluate both the operational benefit and define the communications bandwidth requirements and technical options (including frequency bands, standards, etc.) Architecture options will include those in which the sensor platform itself has the very-high data-rate comms link to a satellite, and other architectures in which there is a High Altitude Platform or UAV which has the satellite link, and this acts as a gateway to the sensor platforms which communicate with it via RF comms (probably at EHF) enabling the sensor platform to operate below cloud level with the gateway above cloud level. Options for optical and RF links to the satellite on both uplink and downlink should also be considered. It is highly desirable that such studies also consider other military requirements for very-high data rate reach-back. All these studies need to take into account the need to share information with Allies, and consider at which point in the architecture such sharing should occur and the standards that are available or require to be developed. An output of the Feasibility studies should be the identification of which technologies implied by each system architecture are mature and which require further research, development and demonstration to re-risk future procurement projects.

4.4.3 National Interest

FRA, GBR, ROU, USA (4).

4.5 Navigational Warfare

4.5.1 Motivation

Positioning, Navigation and Timing (PNT) systems provide information essential to the success of NATO operations. Virtually all military missions and applications will use or rely upon PNT information and more specifically Global Positioning System (GPS) PNT data. Therefore, NATO must develop and implement a Navigation Warfare (NAVWAR) strategy that ensures availability of this information to friendly forces and denies access to potential adversaries. NAVWAR is defined as preventing the hostile use of PNT information while protecting the unimpeded use of the information by NATO forces and preserving peaceful use of this information outside the area of operations.

The NAVWAR mission-level goals of protection, prevention and preservation drive the employment of three operational-level objectives associated with Electronic Warfare (EW): Electronic Protection (EP), Electronic Attack (EA) and Electronic Support (ES). EP involves capabilities and tactics to protect personnel, infrastructure, and equipment from effects of friendly or enemy employment of adversary interference sources that degrade, neutralize, or destroy coalition combat capability. EA involves the use of electromagnetic, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability. EA includes: 1) preventing or reducing an enemy's effective use of Global Navigation Satellite System (GNSS) to execute their military operations through jamming and electromagnetic deception; and 2) employing offensive capabilities that use either electromagnetic or directed energy as their primary destructive mechanism (lasers, radio frequency weapons, particle beams). ES involves detecting, geo-locating and characterizing the sources of intentional and unintentional radiated electromagnetic energy for the purpose of providing situational awareness to coalition forces to enable the employment of tactics to mitigate interference or execution of EA measures to eliminate the interference source.

4.5.2 Areas for Collaboration

The following potential cooperative research topics fall all in the three operational-level objectives detailed above.

4.5.2.1 Pseudolites (or Pseudo Satellites)

Pseudo satellites or pseudolites can be used for several objectives/purposes, from Approach and Landing to local navigational system build up. However, development and use of pseudolites present some issues that need to be thoroughly addressed:

- Pseudolites navigation payload design and optimization
- Ground versus airborne pseudolites, configuration management, synchronization
- Near far effects mitigation

4.5.2.2 Jamming/Anti-Jamming

- Development of smart jammers (combination of BB, CW, NB, swept CW) addressing different GNSS spectrum to be denied, using different patterns and techniques
- Hybridized GPS receivers/jammers, jamming threat localization, jamming threat localization in receiver
- Jamming and anti-jamming in a GPS receiver

4.5.2.3 *Navigation Architectures*

- Development and use of Micro-Electro-Mechanical Systems (MEMS) and nanotechnology for navigation systems: potential performances, architectures and applications
- Combination of CRPA, MEMS INS systems with digital receivers
- Risk assessment

4.5.2.4 *Signal Processing*

This domain encompasses the following potential technical developments that could be beneficial for integrity monitoring, PNT solution determination, advanced hybridizations with inertial sensors but also other sensors, in door GPS/GNSS:

- 100% digital GPS/GNSS receivers (from antenna to PNT solution)
- Ultra integrated hybridization of GNSS/GPS and Inertial systems/sensors
- Ultra integrated hybridization of GNSS/GPS and other systems: data links, radio systems
- Signal processing techniques applied to GNSS receivers (and navigation systems) with specific focus on signal acquisition and anti-jamming performances: fuzzy logic, neuronal networks, particular processing

4.5.2.5 *Timing and Synchronization*

One of the main components for a satellite navigation receiver is the local internal oscillator/clock:

- Development of ultra integrated, high performance (stability, shock resistant for high g's applications) oscillators and clocks for signal generation, timing and synchronization (frequency generation) for GPS/GNSS receivers
- Ultra low volume, low power atomic clocks
- Time sensors for navigation payloads (satellites, pseudolites)

4.5.2.6 *Antenna Development*

- Development of advanced, fully digital, controlled radiation pattern antenna (CRPA) using different nulling, beam steering … techniques. Part of these developments should look at the integration problems and issues of these antennas on small or "non-easy" platforms such as PGM, missiles, munitions, dismounted soldier, small vehicles, UAVs (conformal antennas, use of nanotechnologies).
- Advanced receiver/antenna architectures/pairing: with increased digital techniques and architectures, the maturity of MEMS, nanotechnologies, design and develop the best suitable architecture (where receiver and antenna are just one system and not two systems or equipments connected).

4.5.2.7 *Combined Use of GPS and GALILEO*

The European Union plans to develop, by 2010/12, the GALILEO GNSS. The European Commission has declared that Galileo "must be an open, global system fully compatible with the US GPS system, but independent from it." Galileo will offer a restricted and encrypted Public Regulated Service (PRS), intended for users such as European Union (EU) national law enforcement and internal security agencies, which could be used by NATO in combination with military GPS:

- GPS Galileo receiver architectures design and optimization in a view to enhance anti jamming, acquisition, integrity and general performances of a GNSS receiver
- Advanced crypto architectures: how to conciliate the GPS SAASM component and the PRS crypto chip

4.5.3 National Interest

CAN, EST, NLD, USA, NC3B (4).

4.6 Geospatial Information Systems (GIS)

4.6.1 Motivation

GIS provide data, technology and procedures allowing the exploitation of geospatial information in a way that allow one to produce the information needed in supporting its decisions. All of these three components produce many challenges to the scientific community due to the need to integrate the data produced by more and more performant devices (e.g. hyperspectral and very high resolution instruments) and to exploit new high speed satellite communication assets for making the information available where and when it's needed in an interoperable form. Combined with PNT, satellite communication and high accuracy spatial date GIS can play a very important role in planning and running successful operations.

4.6.2 Areas for Collaboration

Many countries have already started different projects aiming to design a prototype for modern soldier making maximum use of last minute technologies in order to improve the effectiveness and reduce the response time. In addition to weapons, the soldier needs timely and updated information usually offered through a Information System capable to handle both spatial and non-spatial data.

Providing accurate, updated geospatial information during both operations planning and running phases implies efficient data storage and access mechanisms complemented by adequate retrieval information (metadata) through common geospatial ontology compliant services.

Also, the rapid deployment of operational, comprehensive information production tools connected to updated information system and data storage facilities given new communication technology could be subject to future research and common experiments.

Finally, increased capacity of data transfer enabled by new communication technology (SATCOM, 3G) opens new possibilities for extending the availability of GIS functionality by web-based applications.

4.6.3 National Interest

BEL, NLD, ROU, USA (4).

4.7 Use of Commercial Satellite Remote Sensing Information for Maritime Surveillance and Oceanography

4.7.1 Motivation

Until 1994, operation of satellite remote sensing systems was limited to governmental organizations due to costs and security considerations. Remote sensing application development was primarily within the research community and had little operational impact and most nations did not even have direct access to satellite imagery.

In the past decade, however, several private companies such as Digital Globe, Space Imaging, Eurimage, Orbimage, Vexcel and others have developed the capability to obtain imagery from space-based platforms with increasing resolution and quality, such imagery has been made available commercially. For instance, the IKONOS satellite launched by Space Imaging in 1999 was the world's first commercial satellite and could collect black-and-white (panchromatic) images with 1-metre resolution and multi-spectral imagery with 4-metre resolution. Today, DigitalGlobe's QuickBird satellite provides commercial sub-meter resolution imagery of 60-centimetre panchromatic and 2.44-metre multi-spectral. QuickBird also has exceptional geolocational accuracy and an imaging footprint two to 10 times larger than other commercial high-resolution satellites. Additional satellites with increased capabilities are planned to launch in the commercial sector already in near future.

Great success for commercial remote sensing in last decade has been launch of radar satellites, Canadian RADARSAT-1, also ERS-1 and 2, which all operate as active remote sensing units. These satellites are used for various purposes, RADARSAT primarily for ice monitoring, but still methods and applications of active remote sensing develop very fast nowadays, especially operational ones.

Such availability of high-resolution and sometimes operational remote sensing data coincides with an increasing need within NATO to support out-of-area expeditionary operations and, in particular, the NATO Response Force (NRF). Commercially available high resolution imagery provides an opportunity to obtain this information on scales and in regions that were previously unobtainable. NATO nations can benefit from the availability of such data with improved methods to use remote sensing imagery.

Extensive work has been accomplished for overland applications to support both military missions and commercial applications. However, an area of equivalent importance is assessment of the littoral environment and, in general, oceanographic conditions.

4.7.2 Areas for Collaboration

Collaborations for the development of improved tools to use satellite-based imagery data are possible in a number of application areas. First, these include weather and oceanographic applications such as shallow water bathymetry, ocean currents, visibility, surf and wave conditions, sea surface temperature, also surface winds, precipitation. In northern latitudes some other characteristics like sea ice extent, ice thicknesses and snow cover parameters. Second group of applications cover area where satellite-based imagery is used for ship identification and tracking, identification of different targets and automatic classification those for Intelligence and Warning (I&W) purposes. Third area of collaboration could be development of operational applications of active remote sensing data merging with other information e.g. ground-based radars and other observation systems.

4.7.3 National Interest

BEL, CAN, EST, NLD, NOR, PRT, ROU, USA (8).

4.8 Exploitation of Satellite Remote Sensing Data for Change Detection

4.8.1 Motivation

Monitoring of change is frequently perceived as one of the most important contributions of remote sensing technology to the study of global ecological and environmental change.

Digital change detection techniques aim to detect changes in images over time and allow the analyst to quickly focus on items if interest. They can be used as a 'cueing system' to attract the attention of human analysts to 'interesting' digital images from the large number of available images. Change detection implies the comparison of remote sensing images from different moments in time. Different sensors can be used for this purpose. Change detection techniques rely upon differences in radiance values between two or more dates. These differences may be due to an actual change in land cover, or differences in illumination, atmospheric conditions, sensor calibration or ground moisture conditions.

The calibration of data, or standardization between dates, may be necessary, and the accuracy of the image registration is important. Holding resolutions and environmental conditions as constant as possible, is absolutely imperative if anything useful is to be gained from these change detection analyses.

Change detection and mapping using remotely sensed imagery provides a valuable environmental monitoring and management tool. This is a process that involves the use of multi-temporal data sets to discriminate areas of land cover change between dates of imaging. The basic objective is the detection of actual changes from one time to another, but other objectives may be included. For example, the nature of the changes occurring, the extent of changes and the spatial patterns of change may also be of interest. When using remotely sensed imagery it is important to minimize the effects of the angle of incidence of incoming energy and fluctuating environmental conditions associated with seasonal changes. Therefore, it is recommended that the imagery being used be acquired by the same (or similar) sensor, recorded with the same spatial resolution, viewing geometry, spectral bandwidths.

There are a number of digital change detection techniques in relatively common use in the remote sensing community. They include post-classification comparison, multi-date classification, image differencing, image regression, image rationing, vegetation index differencing, principal components analysis and change vector analysis. Unfortunately, few quantitative comparative studies of change detection techniques are available, and there is conflict between the results of these studies. It is concluded that there is no universally 'optimal' change detection technique: the choice is dependent upon the application.

Four aspects of change detection are important when monitoring naturally occurring phenomena: detecting the changes that have occurred, identifying the nature of the change, measuring the real extent of the change and assessing the spatial pattern of the change.

4.8.2 Areas for Collaboration

- Automated coherent change detection techniques.
- Damage assessment for Civil Emergency Planning in Defense Against Terrorism (CEPinDAT).
- Detection of UXO. It developed non-intrusive dual-sensor Unexploded Ordnance (UXO) detection and discrimination systems.
- Land cover change detection (for updating land cover maps and the management of natural resources).
- Moving Target Intelligence (MTI).
- Classification Algorithms: Direct Comparison – "Blinking", Write Function Memory Insertion, Multi-date Composite Image, Image Algebra Change Detection, Post-classification Comparison, Multi-date

Change with Binary Mask, Multi-date Change with Ancillary Data, Manual, On-screen Digitizing, Spectral Change Vectors, Knowledge-Based Vision Systems.

- Degradation of environment as a result of training activities (a significant issue on many military installations).
- Combination of satellite imagery and small to medium scale color aerial photography.

4.8.3 National Interest

BEL, CAN, NLD, NOR, ROU, TUR, USA (7).

4.9 3D Urban Mapping

4.9.1 Motivation

Increasingly NATO nations are being involved in military operations that are radically different from traditional scenarios and that involve operations in towns and cities (the urban environment) that may be occupied by a combination of non-combatants and hostile forces. Additionally, disaster relief operations are often conducted in these urban areas. The term 'urban operations' might also be extended to areas such as normal military operations in complex terrain where, for example, steep valleys and cave complexes are encountered, if these have similar effects to city buildings. These types of operations for NATO and NATO member countries can have high political visibility and be extremely costly in terms of personnel and material resources. Successful urban operations in these areas require detailed and accurate 3D maps of these urban areas. This type of 3D information is necessary for predicting GPS outages due to urban canyons, line-of-sight communications link options and military planning for determining possible sniper threat locations, as just a few examples. For military operations in the developing world, or disaster relief operations anywhere in the world, accurate, up-to-date maps of any type may not be available. An ability to rapidly generate 3D maps for an urban area in near real-time is required.

4.9.2 Areas for Collaboration

There are a number of areas for potential NATO partner collaboration. The first area is in the technical means to generate the 3D mapping data. The range of potential topics in this area include novel sensors, new methods of combining or deploying sensors, the relationship with 'situational awareness' or Combat ID and the impact on platforms. The sensors assessment must consider the command and control aspects of the operations, any front-end processing required (including, potentially, data compression or event detection). Another general area is in assessing the utility of 3D maps (what makes a 3D map useful for urban operations, what are the important features, how fine a resolution, how much latency is acceptable, how large an area is needed, how often should the 3D map be updated?). NATO trials to quantify the important figures of merit would be a useful area for collaboration. Issues of tasking the sensor(s) correctly, precise position determination, shadowing issues and the potential of multiple sensor systems (even of the same type) being used with different noise and resolutions would need to be addressed. Sensor platform deployment and scheduling combined with logistics will need to be analyzed particularly given the probability of poor infrastructure support and/or hostile action.

4.9.3 National Interest

BEL, CAN, EST, FRA, GBR, NLD, ROU, USA (8).

4.10 Space Object Surveillance

4.10.1 Motivation

Space Sensing has become a key part of the tool kit for today's warfighter. NATO uses information from space assets in most of its military operations from situational awareness to space weather. Better understanding and improved situational awareness has now been extended to space operations. The improvements in both ground and space-based sensing to accomplish the full operational picture are required. Coalition forces must also understand the utility of new sensing techniques.

4.10.2 Areas for Collaboration

- Space sensing needs and requirements.
- Phenomenology and field measurements.
- Physics-based performance models.
- Combining sensor technologies.
- Calibration issues.
- Image/spectral processing and fusion.
- Military utility analysis.
- Observable quantities.

Ref: SET-105 Space Surveillance and Situational Awareness

4.10.3 National Interest

BEL, FRA, GBR, NOR, ROU, USA, JAPCC (6).

4.11 Space Debris

4.11.1 Motivation

It has been a common understanding since the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) published its Technical Report on Space Debris in 1999, that man-made space debris today poses little risk to ordinary unmanned spacecraft in Earth orbit, but the population of debris is growing and the probability of collisions that could lead to potential damage will consequently increase. It has, however, now become common practice to consider the collision risk with orbital debris in planning manned missions. So the implementation of some debris mitigation measures today is a prudent and necessary step towards preserving the space environment for future generations.

The Inter-Agency Space Debris Coordination Committee (IADC) is an international forum of governmental bodies for the coordination of activities related to the issues of man-made and natural debris in space. The primary purpose of the IADC is to exchange information on space debris research activities between member space agencies, to facilitate opportunities for co-operation in space debris research, to review the progress of ongoing co-operative activities and to identify debris mitigation options. Members of the IADC are the Italian Space Agency (ASI), British National Space Centre (BNSC), Centre National d'Etudes Spatiales (CNES), China National Space Administration (CNSA), Deutsches Zentrum für Luft-und Raumfahrt e.V. (DLR), ESA, Indian Space Research Organization (ISRO), Japan, NASA, the National Space Agency of Ukraine (NSAU) and Russian Aviation and Space Agency (ROSAVIAKOSMOS).

One of its efforts is to recommend debris mitigation guidelines, with an emphasis on cost effectiveness that can be considered during planning and design of spacecraft and launch vehicles in order to minimize or eliminate generation of debris during operations. The IADC guidelines are based on these common principles and have been agreed to by consensus among the IADC member agencies.

Several national and international organizations of the space faring nations have established Space Debris Mitigation Standards or Handbooks to promote efforts to deal with space debris issues. The contents of these Standards and Handbooks may be slightly different from each other but their fundamental principles are the same:

1) Preventing on-orbit break-ups
2) Removing spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbit regions
3) Limiting the objects released during normal operations

4.11.2 Areas for Collaboration

Potential areas for collaboration in the RTO are to address NATO's use of such guidelines, to adopt mitigation standards and to improve debris models. This could include the investigation of effective engineering and mission design practices to reduce risk of contributing to orbital debris and to prevent damage to spacecraft due to such debris. In addition, with increasing resolution capability of debris sensors, there is a need for methods to improve space debris catalogues and models to include a much larger number of elements. Finally, the use of specialized micro/nano satellites for space debris density monitoring could be investigated.

4.11.3 National Interest

FRA, GBR, NLD, ROU, USA, JAPCC (5).

4.12 Small Satellite Technologies

4.12.1 Motivation

Small satellites offer a number of potential advantages to the future war-fighter. A primary feature of small satellites is clearly that they are significantly cheaper than large platforms, with the result that constellations of small satellites are financially viable. Moreover, the technical capabilities of small satellites have now advanced to the point where they offer significant military utility.

The specific areas where constellations of small satellites can provide most benefit are in terms of responsiveness and robustness. Responsiveness can arise in two ways; partly as a result of the fact that small satellites can be developed and launched quickly in response to a crisis, and partly because constellations can deliver coverage in a far more timely fashion than individual large satellites. Robustness arises from the degree of physical diversity inherent in a constellation, and from the fact that more comprehensive coverage provides a potential adversary with fewer opportunities to act unobserved.

4.12.2 Areas for Collaboration

NATO partners may wish to exchange information regarding small satellites in order to enhance the advantages which these platforms provide. In particular, improvements in areas such as power generation, memory storage capacity, on-board processing capacity, and downlink data rates would all enhance the effective duty cycle of these platforms.

Since small satellites are inherently stable from a structural point of view, they can operate in a more agile fashion. Technologies such as variable speed control moment gyros which could enhance this agility and at the same time could address some of the power storage constraints on the satellites would be of benefit.

Since satellite costs are generally related to their mass, all technologies which would reduce the mass and volume of the components required to perform various functions on-board the satellite would advance the performance per mass ratio.

As well as being used in widely separated constellations, small satellites can be used in clusters to synthesize the capabilities of larger satellite platforms. The control of such clusters is an area where further research is required, with the possibility that terrestrial wireless technologies might be employed to allow the satellites to maintain the desired configuration in space; and also to exchange data where necessary to permit on-board correlation and processing.

The timeliness advantages of small satellites could potentially be enhanced further if long-range inter-satellite link technologies could be implemented successfully on a small satellite platform.

Propulsion technologies which could be used to more efficiently control constellation phasing, and also allow a more flexible concept of operations including maneuvers in time of crisis to adapt the coverage pattern provided, are also desirable.

4.12.3 National Interest

BEL, CAN, DEU, FRA, GBR, ITA, NLD, ROU, ESP, USA (10).

4.13 Satellite Constellations and Formation Flying in the Networked Environment

4.13.1 Motivation

Current space-based ISR capabilities are largely focused on the provision of strategic intelligence information of specific, localized regions in timescales measured in days rather than hours. Whilst such systems clearly have utility in support to high-level operations planning, they are limited in terms of senor footprint area and timeliness of response. Hence, in times of crisis, there is a difficulty in extending space-based surveillance support down to lower levels of command, due the mismatch, (in terms of the areas of intelligence interest and decision cycle times), between what the in-theatre users require and what the current satellite systems can provide.

A further driver is the increasing concern that the long-range airborne surveillance assets are having their performance envelopes eroded by the need to stand-off at ever increasing ranges from new generations of advanced surface to air missiles. The surveillance footprints of these airborne sensors are thus decreasing, at a time when the requirement is for increasing surveillance footprints to counter weapon systems with increased range and mobility.

4.13.2 Areas for Collaboration

NATO partners may wish to exchange information regarding surveillance satellite constellations which can be deployed in response to a particular geographic threat, and which can provide more operational utility, (in terms of area coverage and response times), than the existing strategic systems. Specific trade-offs of interest are likely to include the choice between a small constellation of larger, more capable and more expensive satellites, and a larger constellation of smaller, cheaper and less capable assets.

In view of the aspiration to provide a networked surveillance capability in the future, a further study could involve options to combine different classes of sensors on satellites platforms in more widely separated constellations; or operating in close proximity as part of co-orbital clusters with common access swaths and the ability to provide collocated, contemporaneous coverage.

Another important area of investigation could be the interaction between airborne and space assets, looking at the degree of overlap in performance that would be necessary to achieve successful cueing, and the constraints on the assets' collection times and collection geometries that would permit successful data fusion.

To take this research forward successfully, it is anticipated that some initial work would be necessary to outline the surveillance requirements that need to be satisfied, (acknowledging that certain space-based assets are already in place, or under development, which could satisfy some of these requirements). Assumptions would also be required on the concept of operations for the surveillance component in general, including topics such as the likely areas of operation, and the nature of the communications that might be available to deliver the raw data from the collection platforms to the analysts for exploitation.

4.13.3 National Interest

BEL, CAN, DEU, FRA, GBR, ITA, NLD, ROU, USA (9).

4.14 Emerging Spacecraft Structures and Materials

4.14.1 Motivation

Improvement of the functionalities of spacecraft structures and materials through the integration of electrical, smart sensors, thermal and environmental protection (debris impact and radiation) systems within the spacecraft load carrying capability structural elements is an emerging technology in the space field. This integrated design concept is named Multi-Functional Structures (MFS). Multi-functional structure elements can be used in advanced equipment designs for spacecraft, telecommunication or earth observation satellites, as well as for aircraft and ground transportation systems. The inflatable structure represents a typical example of a multi-functional shell where each layer is dedicated to accomplish a specific task: basically an internal bladder is devoted to air containment, a structural restraint withstands the pressure load and further external layers are focused on protection against micrometeoroids and debris as well as thermal and radiation protection. Their application is extended both manned and unmanned structures (solar arrays, sunshields, solar sails, antennas appendages and reflectors, re-entry-capsule). Another application is on composite sandwich panels that have: electric properties (patch within flexible integrated circuits), thermal properties (heat transfer elements embedded based on high conductivity thermal doublers and straps on high conductive fibers, radiative panels, integrated fluid loops and/or high thermal dissipative materials for encapsulation), environmental protection (EMI/EMC films, impact protection foams) all embedded in the structural panels. The design and development of MFS is based on the use of new advanced materials such as high dissipative fibers, high thermal and electrical conductive materials, nanotubes, metallic foams and integrated active and passive control systems such as capillary fluid loops, close to zero air-tightness polymeric films, high performance composite dry fabrics, dissipative materials, open cell foams, ceramic fabrics, protective films and flexible electronics. Military use of such technology is fundamental for the overall mass reduction of space missions, i.e. increase the payload mass and therefore reduction of the launch cost.

4.14.2 Areas for Collaboration

Within the NATO partners both the owners of the mentioned technologies and the end-users which can benefit of the MFS technology can be identified. The purpose of the proposed activity is to develop prototypes to optimize the design for the areas or products of maximum interest for NATO partners and NATO related applications. Several scaled components or prototypes can be conceived to demonstrate the technological benefit. A trade off with respect to the currently available design solutions shall be performed based on the applicable functional and operational requirements defined by the end-users. The study output should be the definition of a reference design concept and an application development roadmap leading to the prototype configuration definition. This definition will include the identification of all the involved critical technologies and a development approach based on technological demonstrator samples up to the final prototype realization.

4.14.3 National Interest

BEL, ITA, ROU, USA (4).

4.15 Spacecraft Robotics

4.15.1 Motivation

The availability of a satellites servicing space tug capable to perform a rendez-vous and docking with orbiting platforms (either in nominal orbital conditions or stranded) to:

- recover the satellites in the proper orbit
- refuel, re-supply satellites to extend their operative life
- reconfigure and repair satellites

is considered a top priority by the military and civilian space-launch and satellite industry.

Commercial use could be devoted to the recovery to a proper orbit and to the operative life extension of commercial satellites (telecommunication, heart observation) as well as scientific satellites (see the Hubble telescope example, close to end of life and without servicing because of the unavailability of the Space Shuttle). The availability of such technology could support the insurance of launch servicing providing a back-up solution in case of malfunctioning of the third stage of the launcher.

Military use of such technology is fundamental for the maintenance, re-supply and proper operation of the military satellites network, operating for earth observation, early warning or as launcher platform in case of space-based kinetic vehicles.

4.15.2 Areas for Collaboration

NATO partners could identify the areas where, for each of them, this technology will have benefits to better identify the driving set of requirements. The purpose of this first activity is to optimize the design for the areas of maximum interest for NATO partners and NATO related applications.

Several architecture options can be assessed in this first study period, trading the impact of the different operational requirements that will arise from partners needs on the system architecture (flight and ground segment).

A preliminary list of potential trades of costs/risks vs. benefits could include:

- Rendez-vous and docking with purposely designed satellites (Orbital Express concept) versus rendez-vous and docking to satellites not providing standardized docking interfaces (but cooperative)
- Rendez-vous and docking only in Low-Earth Orbit (LEO) versus rendez-vous and docking in highly elliptic or geostationary orbits
- Refuel/re-supply function versus pure recovery to orbit and life extension
- Repair and Maintenance function versus pure recovery to orbit and life extension
- Any other specific need will arise during the preliminary requirements definition

Such studies should also consider the parallel initiatives presently in progress (e.g. Orbital Express, Orbital Recovery Corporation, etc.) to investigate how the arising requirements could be implemented on these “platforms” and how a new system could complement the capabilities already envisaged by these systems.

The exploratory study output should be the definition of a preliminary reference design concept and of a preliminary development roadmap, including the definition of the critical technologies (e.g. rendez-vous

function and sensors, capture and docking mechanisms, robotics for servicing/maintenance/repair), development approach and models.

4.15.3 National Interest

CAN, ITA, NLD, ESP, USA (5).

4.16 Spacecraft Power Systems and Propulsion

4.16.1 Motivation

All military operations have come to rely on space assets for the traditional functions associated with navigation, weather forecasting, communications, surveillance and the like. There is virtually no limit to the potential of space if we can place and maintain systems in orbit economically and reliably and provide adequate electrical power to the payloads for the lifetime of the satellite.

Two technologies pace the degree to which space is exploited for military use: spacelift and spacecraft power.

Affordable spacelift has been the subject of research and development for several decades. Much attention has been given to reusable lift vehicles in the relatively recent past in the hopes of reducing costs. But the solution to the problem is not yet in hand because of a several issues. The most pressing issue is reliability versus cost. The wide range of payload weight and volume and the variety of orbits to which the payload must be raised also contribute to the problem.

The need for adequate fuels for orbital maintenance has prompted new looks at electric propulsion schemes. This area of research has also benefited from a renewed interest in propulsion outside the solar system. In these applications, the need for advanced propulsion and power technologies converge in the sense that the traditional space power system, solar cells coupled to batteries, are no longer an option due to the low solar irradiance. Even in near-Earth orbit, for missions that require more than a few tens of kilowatts of electrical power, alternatives to solar-photovoltaic systems are needed. Batteries and rechargeable fuel cells with higher specific energy and specific power are also needed.

4.16.2 Areas for Collaboration

There are a number of areas where collaboration among NATO nations, including the Partnership for Peace (PfP) members, can make a difference. Affordable, reliable spacelift is a generic problem that all space-faring nation face. The goal of single-stage-to-orbit is rooted in fundamental material issues that can be jointly explored. Spacecraft power systems, including more efficient solar arrays, radiation-hardened solar cells, solar concentrators and even alternatives to photovoltaics can be collaboratively studied. Eventually, nuclear power systems will be needed, and that could also evolve into a collaborative activity. Power management and thermal management are also technology areas in which nations could participate with only a limited investment in space activities.

4.16.3 National Interest

ITA, USA (2).

4.17 Satellite Navigation, Attitude Control, Orbit Determination and Tracking

4.17.1 Motivation

The increase in Earth observation resolutions (i.e. ground sampling distances around decimeter range), satellite attitude determination requirements are becoming more stringent. To realize these requirements, the satellite sensor suite (i.e., sun sensors, star sensors, magnetometers, gyros) shall not only be made more accurate, the signal processing algorithms shall also be developed to supply the attitude information within the accuracy needed to the attitude control system.

The classical attitude control actuators of Earth observation satellites are reaction and momentum wheels. These actuators are quite heavy. Some satellites also carry thrusters for attitude control. However, these systems are not only heavy, the limited fuel brought to orbit determines the useful life of a thruster. Control Moment Gyros (CMGs) are the new class actuators expected to be used more on future satellite missions. With the current off the shelf technology, CMG clusters can weigh many times lighter than reaction or momentum wheel clusters of the same torque (and momentum) capability. It is possible to reduce the weight of the CMG clusters by increasing the wheel speed further.

Another emerging technology is the Integrated Power Attitude Control-Control Moment Gyroscope systems (IPAC-CMG), where spinning wheels are also used to store kinetic energy. The kinetic energy is converted into electrical energy eliminating the need for chemical batteries. In this area, it is necessary to develop high-speed rotor generator systems. Studies have shown IPAC-CMGs can be made much lighter than reaction wheels with nickel cadmium battery systems. Again as the wheels speeds are increased greater weigh savings are possible.

Current orbit determination techniques are based on GPS signals, and ranging methods as well as radar systems. It may be possible to carry out orbit determination using stellar information or using Earth observation images, together with attitude information.

4.17.2 Areas for Collaboration

NATO partners may wish to collaborate on the above areas to conduct feasibility studies to identify the background technologies, current state-of-the-art and critical areas of future research. In particular:

- To examine current attitude determination sensors and processing techniques. Among them, information processing algorithms used in star mappers. Deterministic and probabilistic sensor fusion and attitude estimation algorithms (i.e., Kalman filters, neural networks, etc.).
- CMG and IPAC-CMG hardware. The high-speed motors and motor generators.
- CMG steering algorithms.
- IPAC-CMG steering and energy drainage algorithms.
- Orbit determination from Earth observation data, as well as using stellar information.

4.17.3 National Interest

DEU, ITA, ROU, ESP, TUR, USA (6).

4.18 Space Environment and Space Weather Effects

4.18.1 Motivation

The exposure of satellites and components to the harsh conditions of space is of major concern for their performances and reliability as is being demonstrated in the day-by-day operations including recent NATO experiences. In particular, the following space environment constituents and their effects on systems and components deserve Research and Development (R&D) efforts including careful consideration during the design phases:

- Ionizing radiation
- Meteoroid & Orbital Debris

The study and prediction of space weather by integration of data resulting from multiple satellites and detectors and forecasting systems for SEP precursors is a key element in this respect.

4.18.2 Areas for Collaboration

Research is proposed in two areas:

1) Ionizing Radiation:
    - Accurate modeling of the solar energetic particle environment, by updating standard models developed based on results published more than 10 years ago and of SEP precursors
    - Improved capability of prediction of space weather by integration of data resulting from multiple satellites and detectors, forecasting systems
    - Development of “Sentinel” spacecraft, e.g. SOHO follow-on, Near-Side and Far-Side Sentinels Prediction
    - Development of ground-based monitors (imaging, radio, etc.)
    - Validation of ionizing radiation ground test results against in-orbit behavior

2) Meteoroid & Orbital Debris:
    - Improvement of the capability to assess the vulnerability of spacecraft under meteoroids and orbital debris impacts, with specific attention to:
        - Review of unexplained on-orbit anomalies
        - Selection of critical satellite functions and subsystems
        - Debris cloud propagation within the satellite bus
        - Testing of mechanical, contamination and electromagnetic effects induced by hypervelocity impacts on satellites structures and components
        - Potential damage to external equipment and sensors
        - Simplified and updated meteoroids prediction
        - Debris vulnerability assessment of selected satellites in polluted orbits

These activities may be partially or totally carried-out in the NATO environment or outside this environment but carefully followed and tracked by a NATO RTO team.

4.18.3 National Interest

BEL, GBR, ITA, ROU, USA (5).

4.19 Systems of Systems for Early Warning

4.19.1 Motivation

A spaceborne early warning system is, in essence, a multi-national cooperative asset. The nature of the threat to be detected is in general a large scale, cross border effect weapon. Data exchanges and interoperability are generally part of the basic system requirements.

Starting from the raw information (image or non image) taken by the satellite, a complex process has to be run to reach a primary alert message with an acceptable false alarm rate. Here the information can be enhanced/fused with other intelligence sources to reach an elaborated alert message to various "clients" or missions. In these processes, data bases are deeply integrated.

Several nations can join to develop such a system, even if they don't share the same views on primary missions to be served by this sensor (active defense, passive defense, proliferation control, contribution to deterrence, counter force, space surveillance…). One nation may have as a priority the defense of projected forces on theatres abroad, another the protection of territories and homeland, in an active or passive format, and a third body might only be interested in monitoring proliferation.

If all can share the same sensor, and data trunk, what can be imagined to enable data exchanges at various levels of processing, respecting the policies of each nation, respecting and the confidentiality of each treatments?

4.19.2 Areas for Collaboration

The focus of the research is on the exchange levels of the information provided by the system. The main questions to answer are:

- At what level of the processing chains, data exchanges are feasible?
- How the different systems may be interconnected?
- How can we deal with the classified data that are surely involved in the processing chains?
- How the common trunk of a cooperative system can be operated by one body, with the full confidence of all the participants?

This could lead to an interoperability recommendations for future systems and/or recommendations for external users to connect and acquire alert messages from an existing system.

4.19.3 National Interest

BEL, EST, FRA, ITA, ROU, USA (6).

4.20 Atmospheric Propagation and Mitigation Techniques

4.20.1 Motivation

Earth observation from EO/IR sensors is directly affected by cloud coverage; for high resolution synthetic aperture radar (SAR) and interferometric SAR, some decoherence due to the troposphere has been reported. For both EO and microwave observation, mitigation techniques would then be restricted to accurate nowcasting of the weather conditions for optimizing the data gathering pattern of the spaceborne sensors.

For SATCOMs, various effects of the troposphere are to be considered depending on the radiofrequency:

- Molecular absorption, potentially causing attenuation for EHF bands and raising noise temperature of ground antennas
- Cloud scattering and absorption, also mostly effective at EHF
- Scattering by rain, hail and snow, with significant attenuation or cross-talk effects at centimetric wavelengths, and increasing for shorter wavelengths

Since EHF band offers much wider available bandwidths than the presently crowded C to Ku bands, together with reduced antenna size, it is of major interest for future SATCOM systems. An added value for military applications is a potentially increased robustness to interception or jamming thanks to smaller beamwidths and more efficient spread spectrum techniques.

The adverse effects of atmospheric propagation on EHF earth-space links have therefore to be accurately understood and efficiently corrected through fade mitigation techniques. Among those techniques, adaptive reduction of channel capacity fits with military procedures where top priority messages can be extracted from routine.

4.20.2 Areas for Collaboration

There is already through ITU-R and EU COST groups a lot of collaborative work dealing with improved analysis of tropospheric effects and mitigation techniques for civilian SATCOMs up to Ka band. It is therefore suggested that NATO should concentrate on specific aspects for military communications, like following:

- Propagation data and mitigation techniques for the upper EHF band
- EW aspects of SATCOMs
- Diversity benefits for a fleet deployed in tropical and equatorial climates

4.20.3 National Interests

EST, NLD, ROU, USA (4).

4.21 Image and Data Compression Algorithms for Remote Sensing and Communication

4.21.1 Motivation

Optical and SAR payloads on board EO-satellites are generating ever-larger quantities of data due to the increase of spatial and spectral resolution and capacity. Notwithstanding the progression in the development of data link and ground segment technologies, the need for improved data compression on board the satellite is growing, in order to use the payload capacity as efficient as possible and achieve maximal area coverage rate.

Therefore new data reduction approaches are to be explored, including the suitability of advanced compression techniques for on-board implementation; the relation between allowable compression noise and required application-product quality; the combination of compression with on-board payload data (pre)processing; flexible and instantaneous spatial and spectral resolution adaptation corresponding to momentary operational requirements; and on-board cloud avoidance techniques for optical payloads.

The data compression element is also of importance with respect to data and network security. Its place, function and performance as part of a security architecture (in combination with encryption) in space-based communication and remote sensing networks has to be further explored. Higher data throughputs and increased security levels require faster encryption technology, both hardware and software, that is appropriate for space implementation.

4.21.2 Areas for Collaboration

- With respect to SAR data compression, the focus is on:
    - development and evaluation of image domain compression algorithms, including polarimetric and interferometric data,
    - development and evaluation of frequency domain compression algorithms, and
    - understanding of application product quality versus allowable compression noise based on integrated simulation.
- With respect to Multi-/Hyperspectral data compression, trade-off analyses are to be performed between compression noise, product quality, and implementation complexity for various compression variants.
- Cloud avoidance scheduling techniques for optical remote sensing.
- Research on faster encryption and decryption processes (HW and SW).
- Compression techniques and security architectures.

4.21.3 National Interest

BEL, NLD, ROU, TUR, USA (5).

4.22 Near Real-Time Automatic and Semi-Automatic Multi-Sensor Data Fusion

4.22.1 Motivation

Data fusion means a very wide domain and it is quite difficult to provide a precise definition. Several definitions of data fusion can be proposed:

- Image fusion is the combination of two or more different images to form a new image by using a certain algorithm which is restricted to image.
- Data fusion techniques combine data from multiple sensors and related information from associated databases, to achieve improved accuracy and more specific inferences that could be achieved by the use of single sensor alone. This definition is focused on information quality and fusion methods.

Both methods are able to give the situation awareness of the scene and give the supremacy deriving from the information superiority. The principal military application is the Intelligence application for tactical purpose or for strategic vision. The fusion of images can be done between SAR and electro-optical image or from other different kinds of sensors. With the data fusion process it will be possible to do:

- Correlation – to collapse different information objects of the same type representing the same physical observation into a single object of the same type such as deriving a single coherent track from different track generators.
- Data Combining – to enhance the knowledge about specific physical observed objects by combining input from different classes of objects such as using a passive observation sensor to enhance a track with unique identity information.
- Fusion – to create new classes of knowledge by creation of new information objects from known information objects and the knowledge being of a type not inherent in the input objects.
- Filtering – to remove unwanted or unnecessary information content or structure from data inputs in order to produce new information output.
- Searching – to carefully explore or examine a collection of information objects, or the contents of one or more of those information objects, in order to acquire and output the particular information that is desired.
- Monitoring – to observe, record, or detect a condition, such as noting a particular change in state of an information object by observation of changes across a set of versions of that information object.
- Evaluation – to examine in a predefined way a set of information object types and values to arrive at some publishable conclusion (e.g. for decision making).
- Collation – to compare different information objects to locate points of agreement or disagreement and arrange data elements into one or more new information objects that exhibit the desired order/format/composition of the information.
- Updating – to revise the values of information object attributes or payload and produce a new version off that object.
- Sorting – to arrange information object elements with respect to some order to produce new information output.

4.22.2 Areas for Collaboration

There are a number of areas for potential NATO partner collaboration. NATO partners can:

- Develop a common software and application to fuse the different images.

- Produce a list of product to extract from the process of data fusion.
- Evaluate high performance computing technologies, such as parallel computing, in order to achieve efficient high throughput data processing (fusion).
- Evaluate technologies, define methodologies, protocols and standards that can be applied to the design and the architecture, taking into account interoperability, modularity and extensibility of the resulting framework; study emerging protocols connected with Web Service and Open Grid Service Architecture and widely used within grid environments.
- Define the structure/network and database (schemas and metadata) to exchange information; analyze data integration problems related to data consistency, data format and semantic heterogeneity of the data sources, naming conflicts, etc.
- Design a computational grid, specialized for this context, which:
  - (i) provides availability, efficiency and security,
  - (ii) transparently extends the physical framework adding and deleting new resources,
  - (iii) decreases the time to process the data,
  - (iv) joins data stored in heterogeneous data sources in a transparent way, and
  - (v) reuses the existing physical framework, optimizing the usage of computational resources.
- Designing and developing a high level services toolkit that includes: Data combination service, data correlation and fusion service, data searching and filtering service, resource monitoring. These services will leverage on the understanding middleware services and on the low level data management services.
- Designing and developing of a web-based access point to the services and grid infrastructure. The Grid Portal main function is to mediate between the user's request and the Grid offering thus hiding the complexity of the available services. The Grid Portal will provide also an integrated environment for accessing high level services to data access and to data fusion by means of proposed software, which: efficiently uses of the computational resources, efficiently handles jobs, provides fault tolerance and fault recovery mechanisms.

4.22.3 National Interest

BEL, ITA, NLD, ROU, USA (5).

4.23 Satellite and Sensor Protection

4.23.1 Motivation

Today military operations become more and more dependent on space related infrastructure. As a result it is interesting for hostile forces to be able to:

- Prevent the utilization of allied space infrastructure
- Take over and use allied space infrastructure against NATO countries
- Derogate or destroy allied space infrastructure

Potentially there are two kinds of hostile actors:

- Countries with own space capabilities, which use space assets also as force enhancer
- Countries without or limited space capabilities including non-state-actors, which are not dependent on space infrastructures

Therefore, in addition to the ground segment, allied satellites are a potential target of hostile activities and have to be protected.

4.23.2 Areas for Collaboration

Collaboration within the member states can be related to technological approaches. Typical examples are:

- Cryptography
- Impact shielding
- Radiation hardening
- Protection filters for sensors
- Attack identification

The second field of collaboration regards the application of the national capabilities in an alliance wide network approach. This can result in a highly:

- Increased redundancy
- Cost efficiency because of international division of labor
- Improved performance because of the combination of different capabilities

Therefore interoperable concepts have to be defined and designed.

4.23.3 National Interest

DEU, USA (2).

4.24 Upper Atmospheric Research

4.24.1 Motivation

The atmospheric density in the upper atmosphere varies on various timescales and length scales. This is known qualitatively for:

- solar cycle variations
- solar storms (Coronal Mass Ejections)
- planetary waves
- tidal waves
- atmospheric gravity waves,

but the absolute or relative variations in a given situation, and depending on season, latitude, or time of day are not well known. Better knowledge of these phenomena including prediction will improve our planning for:

- LEO satellite drag
- Re-entry vehicle trajectories
- Refractive index variations and fluctuations for optical communication and remote sensing

4.24.2 Areas for Collaboration

Upper atmosphere research institutes, or research groups, exist in many countries and collaborate already on selected scientific issues. Some of these groups or institutes are military, but only few. Upper atmosphere research is for the most part basic science (“curiosity-driven”).

It would be useful to start up collaborative research for mapping and quantitative description of each of the above five phenomena with the aim of predictions. At the same time the same groups, or more applied research groups, should be encouraged to study the interactions of the three applied points above with those geophysical phenomena.

These activities may be partially or totally carried-out in the NATO environment or outside this environment but carefully followed and tracked by a NATO RTO ad hoc team.

4.24.3 National Interest

EST, NOR, ROU, USA (4).

4.25 Ionospheric Research

4.25.1 Motivation

Communication between ground and satellites involves the propagation of radio waves through the ionosphere. This media has properties which are governed by parameters which are non static. Near real-time monitoring is required to exploit the full data through-put from a fixed site. A project is proposed which will measure inter alia total electron content Total Electron Content (TEC) and radio scintillation.

Beacons were installed on the early spacecraft and measurements taken over a number of years, so the principles are well established. The new constellation of radio beacons called the Coherent Electromagnetic Radio Tomography (CERTO) will be available for measurements of ionospheric total electron content and radio scintillations. These beacons transmit unmodulated, phase coherent waves Very High Frequency (VHF), UHF and L-Band frequencies. TEC can be measured using the differential phase technique. The range between beacon and receiver is removed from the phase measurements leaving a differential phase that is proportional to TEC. The three CERTO frequencies cover a wide range to determine the radio scintillation effects caused by diffraction after propagation though ionospheric irregularities. All of the CERTO beacons are in low-earth-orbit with inclinations ranging from equatorial to polar. Each satellite that carries CERTO has other plasma instruments that complement the beacon data.

New algorithms have been developed to use the three frequency CERTO and CITRIS data for improved acquisition and analysis of TEC and scintillation data. The data from the CERTO constellation of beacons and receivers may be used to update space weather models.

4.25.2 Areas for Collaboration

The purpose of collaboration is to establish measurement sites to cover as much of the globe as possible. A void in the ground-based receiver locations is observed in and around the Mediterranean region which would be filled if the proposal is implemented in NATO Europe. The primary cost of launching the beacons will be absorbed by the US which leaves the cost of a receiver and the associated costs of an engineer to take and record the measurements.

4.25.3 National Interest

EST, ROU, USA (3).

4.26 Space-Based Radar Technology and Applications

4.26.1 Motivation

SAR systems operating at a frequency of 10 GHz have two unique features compared to optical or infrared sensors: first, the image acquisition is almost independent on day- or night-time and on the visibility conditions of the atmosphere; second, the size of the spatial resolution cell is independent of the distance between target-sensor and of the wavelength for ideal processing. Therefore SAR sensors on space borne platforms fulfill to a high degree the requirements of the military user. These requests are on one hand the sufficient for detection, recognition and identification, and on the other hand for a broad spectrum of applications, e.g. worldwide reconnaissance, surveillance, catastrophe monitoring, border control, etc. In this context, the most important image quality parameter is the spatial resolution. Present space-based system achieve values for spatial resolution in the order of about 1m. Looking into the US National Imagery Interpretability Rating Scale (NIIRS) especially for the identification of targets, a much better spatial resolution is necessary.

SAR sensors are very complex systems with several hundreds of parameters to optimize. At the moment there are no general ways of system design and evaluation. Therefore the optimization of space-based systems and missions the performance parameters (e.g. radiometric resolution, dynamic range, ambiguity suppression, orbit determination, etc.) have to be optimized very carefully.

4.26.2 Areas for Collaboration

- Development of inflatable antennas with diameters larger than 10m
- HF power generation
- Development of methods for automatic geo-referencing
- Development of analysis methods for polarimetric target signatures
- Highly accurate orbit determination (inclusive geophysical parameters, etc.)
- Development of phase preserving processing techniques for SAR interferometry
- Design of SAR systems for wideband multi-frequency systems with polarimetric and interferometric capabilities, e.g. for the generation of digital elevation models, reference signatures (if they are not already existing in other groups)
- Development of mathematically complex modules for SAR end-to-end simulation
- Development of criteria for the evaluation of existing and future space-based SAR systems
- Development of algorithms for change detection (e.g. coherence analysis)
- Data fusion of SAR, optical, infrared and hyperspectral data

For all these proposed activities the mutual exchange of technical expertise is beneficial within the Research and Technology Agency (RTA) community.

4.26.3 National Interest

BEL, CAN, DEU, FRA, ITA, NLD, NOR, ROU, TUR, USA, NURC (10).

4.27 Space-Based Multi- and Hyperspectral Sensors Technology and Applications

4.27.1 Motivation

Hyperspectral-based IMINT data can bring a decisive advantage. The operational missions are potentially numerous and can be arranged in two groups:

- The first is related to automated exploitation of natural data (e.g. pedology, soil passability, beachability, shallow bathymetry, illegal culture detection) and reconnaissance of non natural assets (e.g. camouflage, concealment & deception countermeasures). This group of applications is mainly based on natural signatures – chlorophyll for example.
- The second group gathers missions related to element reconnaissance/identification (e.g. gas, land mines, sea mines), for surveillance missions or counter proliferation missions. This group of applications needs a good knowledge of individual signatures.

Hyperspectral data treatment has to take into account the local conditions, the lighting conditions, the transfer thru the atmosphere and the nature of the instrument. The resulting data might be used in autonomous systems, or fused with standard high resolution images (radar or optical).

Despite the complexity of these techniques, commercial applications (precision farming) are already in operation, and mil experts are stating the hyperspectral imaging shall be the IMINT revolution in the next 20 years. This domain is reasonably accessible.

4.27.2 Areas for Collaboration

The field of investigation is extremely wide, and many countries have already developed R&D lines on these topics. Nevertheless, a cooperative research can be defined. A moderate ambitious topic such as Group 1 mission operational evaluation is proposed here.

4.27.3 National Interest

BEL, CAN, DEU, EST, FRA, ITA, NLD, NOR, ROU, TUR, USA, NURC (11).

4.28 Use of Surveillance Sensors for Moving Target Indication (MTI)

4.28.1 Motivation

Airborne ground moving target indication (GMTI) has proved very useful in surveillance, allowing commanders to have a birds-eye view of what's happening on the ground. Space-based sensors for moving target indication could enable surveillance for moving targets over wide areas and distant theatres. This could prove useful to NATO especially in the early stages of a conflict, when airborne assets may not be in theatre. However, such sensors are not available. Moreover there are significant differences between space borne and airborne cases in look geometries and clutter spectra. With the advent of new commercial space sensors, such as RADARSAT-2, new opportunities exist for shared R&D in these areas.

4.28.2 Areas for Collaboration

Potential areas for collaboration include the following:

- Concept development and exploration
- Simulation and modeling:
    - Sensor systems
    - Cueing
    - Targets in clutter
- Algorithm development for detection of moving targets and estimation of speed and heading
- Algorithms for fusion with imagery data
- Experiments with commercial space-borne sensors

4.28.3 National Interest

BEL, CAN, ITA, PRT, USA (5).

4.29 Radar Polarimetry from Space

4.29.1 Motivation

An electromagnetic wave is preliminary determined by its wavelength, frequency, amplitude, phase and polarization. In many SAR-systems the agility in frequency and polarization is used for an augmentation of the information content of the signatures, of military targets within their background. The added value of polarimetry for radar remote sensing has been claimed for years, with the capability of deriving bare soil roughness characteristics or distinguishing various cultivated areas. A combination with interferometric measurements was later recognized to give access to biomass. Nevertheless the added costs of polarimetry for a spaceborne remote sensing radar slow down the deployment of such new payloads. For military reconnaissance and surveillance missions radar polarimetry has to demonstrate its potential for detection recognition and identification of small targets and infrastructure. Up to now the great lack of radar systems with real aperture was the pure angular and spatial resolution. Future SAR-systems like RADARSAT-2 and Terra-SARX will have a polarimetric capability with a spatial resolution with 1 and 2 m. Their data products are better suited for polarimetric signature analysis.

4.29.2 Areas for Collaboration

- Analysis and evaluation of space borne polarimetric SAR-system.
- Analysis and evaluation of polarimetric calibration methods.
- Definition of common scenarios for target and background measurements.
- Creation of a common data base.
- Development of algorithms for target detection, recognition and identification.
- Development of algorithms for generation of a complete recognized environmental picture.
- Derivation of methods for the polarimetric recognition and identification of dominant scatterers.

Many of these items are investigated in many NATO-countries, but a complete and reliable analysis is missing. At the moment two Sensors & Electronics Technology (SET) Task Groups (SET-053 on “Ground Target Automatic Recognition by Radar” and SET-102 on “High Resolution Spaceborne SAR Systems for Geospatial Intelligence”) address some aspects of SAR polarimetry.

Further specific collaborative activities could concentrate on detection and identification of foliage covered targets. Models could be made available, together with airborne data for assessing potential performances of space borne sensors, and selecting design parameters for future systems.

4.29.3 National Interest

BEL, DEU, CAN, NOR, ROU, TUR, USA, NURC (7).

5.0 NATIONAL RTO SPACE EXPERT CONSULTANT (SEC) POINTS OF CONTACT

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Spaceborne radar
Spacecraft
Spacecraft materials
Spacecraft power
Spacecraft propulsion
Spacecraft robotics
Spacecraft structures
SSTAG
Strategy
Tracking
UHF Antenna systems for SATCOM applications

14. Abstract

As NATO and Nations are facing increased global responsibilities for security and defence with smaller forces, the ability to meet objectives will increasingly depend on use of integral, force-enhancing support from space. To respond to this future need, the RTB established a limited-life, RTO Space Science and Technology Advisory Group (SSTAG) to identify and recommend space research topics to the RTB and RTO panels. SSTAG Recommendations for space research topics were defined through a peer review process involving panel members and external colleagues from the extensive RTO Space Expert Consultant (SEC) network. As part of this, an RTA Space Strategy Workshop was held at RTA HQ in June, 2005 that resulted in 29 topics of common national interest. The topics were developed by members of the SEC network through Summer and Fall, 2005. The SSTAG also sought national support for the topics through Fall, 2005. The effort was supplemented by a SSTAG high level view of relevance to NATO Capability Needs. The SSTAG is seeking Panel consideration of the SSTAG Recommendations as new or extended panel technical activities. Each Panel is being requested to identify topics which have potential as technical activities within the Panel; to indicate if the Panel is willing to take a leadership role in any of the topics as a Panel or Inter-Panel technical activity; and to identify on-going activities within the 2006/7 Program of Work that may be addressing technical topics related to the Recommendations.

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